A Multistage Negotiation Mechnism for Recycling Waste Electrical and Electronic Products based on Bayesian Learning Model

Xinquan Ge, Li LI, Jian Zhang, Xiaozhe Yun

School of Economics and Management, Beijing Information Science and Technology University, China

No. 12 of the Qinghe Xiaoying East Road, Haidian District, Beijing, China

xqge2001@yahoo.cn; lilinw2001@126.com; zhangjian@bistu.edu.cn; xzy315@126.com

Abstract

There are many issues need to be studied for constructing China's waste electrical and electronic products recovering system, and how to determine the levying standard and subsidies standard for recovering the waste electrical and electronic products fund gallery is one of the most urgent problems need to be currently solved. The paper firstly analyses the game behaviours of the manufacturers, recyclers and government, and then designs a multistage negotiation mechanism for determining the levying fee standard and subsidies standard under incomplete information environment, the negotiation process is thoroughly analysed, the condition of convergence is also provided. According to the characteristics of the negotiation, a Bayesian learning model for the government is constructed to update knowledge. The final simulation proves that the outcomes of the proposed multistage negotiation mechanism are closer to the Nash equilibrium, while the Bayesian learning model can reduce the negotiation time and increase the negotiation efficiency.

Keywords

Waste Electrical And Electronic Products; Recycling Mechanism; Multistage Negotiation; Bayesian Learning

Introduction

In recent years, along with the rapid development of China's national economy, people's living standards have dramatically improved, and the demand for electrical and electronic products also significantly increased. At the same time, the scrapping of electrical and electronic products in China also entered the peak period. As the waste electrical and electronic products contain a lot of plastic, steel, glass, nonferrous metals and precious metals, the improper handling of these resources will produce large amounts of pollutants for the soil, water, thus affect the human health. As a result, China had proposed the 'Waste electrical and electronic products recycling Management regulations' on August 20, 2008 at the No. 23 State Council executive meeting and which had put into practice on January 1, 2011. This document intended to establish a standardized and scientific waste electrical and electronic products recovering system with the core is to establish a special fund gallery for recycling the waste electrical and electronic products, in which the sources of funds are the recycling fees levied to the manufacturers. The funds are mainly used to subsidize other professional recyclers. In order to increase the transparency of this program, the establishing of the standards for collecting and recycling fund fee and subsidies should be fully listen to the advices of the electrical and electronic product manufacturing enterprises, processing enterprises, relevant industry associations.

As can be seen from the above provisions, the key to establish a special fund gallery is to determine the levying standard and subsidy standard. The development process is actually a game process among the government, manufacturers and recyclers. In order to get the best resources configuration, the government certainly hopes that waste electrical and electronic products should be recovered by the company with the highest recovery efficiency, no matter it is a manufacturer or a professional recycler. However, as a profit-maximizing independent legal entity, these companies may deceive the government by reporting unreal recovering return since their income may be reduced by higher levying standard or lower subsidy standard, which means that the government is the loser of the information, so it is necessary to design a reasonable negotiation mechanism to reduce the likelihood of irrational allocation of resources due to incomplete information.

Some of the current researches in China on waste electronics recycling mechanism are mainly qualitative analysis focusing on the summaries of lessons learned abroad [1-3] and recommendations for establishing recovery mechanisms policy [4-7]. There is also some quantitative analysis, as He [8] used the Stackelberg game to study the interests of manufacturers, distributors, consumers and governments in the case of Different Stakeholders in waste electrical and electronic product recycling mechanism. Ma [9] uses the dynamic game theory to build waste electrical recycling products model in line with China's national conditions. Wang [10] designs an incentive mechanism to motivate manufacturers to maximize the recovery of waste electrical and electronic products. The results of these researches provid a theoretical reference for establishing a scientific waste electrical and electronic product recovering mechanism in China, with less guidance for determining a reasonable fund fee charged standard and subsidy standard. Most of the current researches regards to this topic are some policy recommendations, which cannot effectively guide the actual operation, so it is very necessary to construct the methods to determine a reasonable fund fee charged standard and subsidy standard.

This work firstly builds the game models among the government, manufacturers and processing company for determining the levying standard and subsidy standard, which can be seen in part 2; and then we built a multistage negotiation mechanism for the government to force the manufacturers and recyclers to bid actual information about their recovery returns and costs, this will be shown in part 3; after that, a Bayesian learning model is introduced to improve the negotiation efficiency, which will be clarified in part 4; part 5 will presents a simulation to illustrate the process of the mechanism constructed in this work and the final part concludes this work..

The Game model

Manufacturers' Recovery Decision-making Process

The manufacturers will determine the quantity of self-recovering and recycler-recovering waste electrical and electronic products based on the level of levying fee standard that the government formulated and also their own conditions.

1) Manufacturers' Recovering Costs

For manufacturers, the cost of recovering electronic waste is mainly generated by two ways: self-

recovering costs and recycler-recovering costs.

The self-recovering costs contain all kinds of costs for operating and managing the recycle station built by their own and also the investment, operation and maintenance costs. The self-recovering costs are expressed as a quadratic function in order to facilitate the subsequent analysis, that is,

$$C_{g1i} = a_{gi} + b_{gi}q_{g1i} + c_{gi}q_{g1i}^2 \qquad (1)$$

Where Cgli represents the self-recovering costs of manufacturer i (i=1, 2…, n), qgli is its self-recovering quantity of waste electronic and electrical products, agi, bgi and cgi is the costs coefficient.

The recycler-recovering costs of the manufacturer i are the levying fee it turned over to the government, that is,

$$C_{g2i} = p_1 q_{g2i} \qquad (2)$$

Where Cg2i represents the recycler-recovering costs of manufacturer i, and p1 is the unit levying fee it turned over to the government, and qg2i is the quantity of waste products that the recycler recovered from manufacturer i.

It is expected that the total of qgli and qg2i should be equal to the total amout of waste electronic and electrical products that the manufacturer i produces and consumed by the customer, so,

$$q_{gi} = q_{g1i} + q_{g2i} \qquad (3)$$

Where qgi is the the total amount of the waste electronic and electrical products that manufacturer i produces.

2) Manufacturers' Recovering Income

When the manufacturers choose the self-recovering way, they may get some income, this is mainly because some parts of discarded electronic products are reusable, which can save part of the production materials purchase costs, that is,

$$R_{g1i} = r_{gi}q_{g1i} \qquad (4)$$

Where Rgli is the recovering income of manufacturer i, and rgi is the unit recovering return.

3) Manufacturers' Recovering Decision-making

Combination of the above analysis, the problem of

a manufacturer's recovering decision can be described as,

The objective function is to maximize the recovering profits, that is

$$P_{gi} = \max_{q_{g1i}, q_{g2i}} \left[R_{g1i} - C_{g1i} - C_{g2i} \right] = \left[r_{gi} q_{g1i} - a_{gi} - b_{gi} q_{g1i} - c_{gi} q_{g1i}^2 - p_1 q_{g2i} \right]$$

(6)

$$q_{gi} = q_{g1i} + q_{g2i}$$ (7)

Deriving the function and defining $\partial P_{gi} / \partial q_{g1i} = 0$, $\partial P_{gi} / \partial q_{g2i} = 0$, we can get the optimal solution of qg1i and qg2i as

$$q_{q1i} = \frac{r_{gi} + p_1 - b_{gi}}{2c_{gi}}$$ (8)

$$q_{q2i} = \frac{2c_{gi}q_{gi} - r_{gi} - p_1 + b_{gi}}{2c_{gi}}$$ (9)

The solution suggests that the lower the fee the government levied, the fewer waste products that the manufacturer will recover by itself and the more it transfers to the recyclers.

Recyclers' Recovery Decision-making Process

1) Recyclers' Recovering Costs

The waste electronic and electric products' recovering costs of the recyclers contain recovering equipment investment costs, operating costs and management costs, which will be expressed as a quadratic function, that is,

$$C_{sj} = a_{sj} + b_{sj}q_{sj} + c_{sj}q_{sj}^2$$ (10)

Where Csj is the recovering costs of recycler j (j=1,2,…, m), and qsj is the quantity of waste products that the recycler recovered, asj, bsj and csj are the cost coefficients.

2) Recyclers' Recovering Income

The recovering income of the recyclers mainly includes two parts: one comes from government subsidies, and the other part comes from the use value of waste electronic and electric products, thus the recyclers' recovering revenue can be calculated by the following formula:

$$R_{sj} = (p_2 + r_{sj})q_{sj}$$ (11)

Where Rsj is the recovering income of recycler j (j=1,2,…,m), and p2 is unit subsidies the recycler j

received from the government, and rsj is the unit income the recycler j earned from recovering and resale the waste electronic and electric products.

3) Recyclers' Recovering Decision-making

The goal of the recycler is to earn the maximum recovering profit, so the objective function can be expressed as,

$$P_{sj} = \max_{q_{sj}} [R_{sj} - C_{sj}] = [(p_2 + r_{sj})q_{sj} - a_{sj} - b_{sj}q_{sj} - c_{sj}q_{sj}^2]$$ (12)

Deriving the function and defining $\partial P_{sj} / \partial q_{sj} = 0$, we can get the optimal solution of qsj as

$$q_{sj} = \frac{p_2 + r_{sj} - b_{sj}}{2c_{sj}}$$ (13)

The solution shows that the higher the subsides that the government provides for the recycler, the more waste products they want to recover.

The Nash Equilibrium Solution of the Government Decision

The goal of the government is to maximize the total social benefits of the recovering process, so the objective function could be expressed as

$$P_g = \max_{p_1, p_2} [\sum_{j=1}^{m} R'_{sj} + \sum_{i=1}^{n} R'_{gi}] = [\sum_{i=1}^{n} \left(r_{gi}q_{g1i} - a_{gi} - b_{gi}q_{g1i} - c_{gi}q_{g1i}^2 \right) + \sum_{j=1}^{m} \left(r_{sj}q_{sj} - a_{sj} - b_{sj}q_{sj} - c_{sj}q_{sj}^2 \right)]$$

Subject to

$$\sum_{i=1}^{n} q_{g1i} + \sum_{j=1}^{m} q_{sj} = \sum_{i=1}^{n} q_{gi}$$ (14)

Equ.(8)

Equ.(13)

Solving the above constrained extreme problem could get the optimal solution of p1 and p2, and we mark them as p1* and p2*,

$$p_1^* = p_2^* = \frac{\sum_{i=1}^{n} q_{gi} - \sum_{i=1}^{n} \left(r_{gi} - b_{gi} \right)\theta_{gi} - \sum_{j=1}^{m} \left(r_{sj} - b_{sj} \right)\theta_{sj}}{\sum_{i=1}^{n} \theta_{gi} + \sum_{j=1}^{m} \theta_{sj}}$$

$$\theta_{gi} = \frac{1}{2c_{gi}}, \quad \theta_{sj} = \frac{1}{2c_{sj}}$$ (15)

The Designing of Multistage Negotiation Mechanism

An important assumption of the game model constructed by the previous section is that the

information is complete known by the government, manufacturers and recyclers, however that may not the truth in reality. Because it is difficult for the government to gather all the costs and income information of the manufacturers and recyclers, the Nash equilibrium solution cannot be easily got by this asymmetry information. That means it is very necessary for the government to develop a negotiation program which can force the manufacturers and recyclers reveal more information about their recovering income and costs. Compared to a single stage negotiation, multistage negotiation mechanism enables the negotiating parties fully access to market information, in order to avoid the blindness of the decision-making, and thus improve the negotiations efficiency [11-13]. In view of this, we designed a multistage negotiation mechanism under incomplete information to help government to get more information and make reasonable decisions on the recovering levying fee and subsidy standard.

Fig. 1 shows the flow that we designed for the multistage negotiation. The entire process involves three decision-making bodies, those are the government, manufacturers and recyclers. The government's main decision-making variables are the levying fee standard and subsidy standard. The manufacturers' main decision-making variables are the quantity of self-recovering waste products and the quantity they transfer to the recyclers. The recyclers' main decision-making variable is the amount of waste products they will recover.
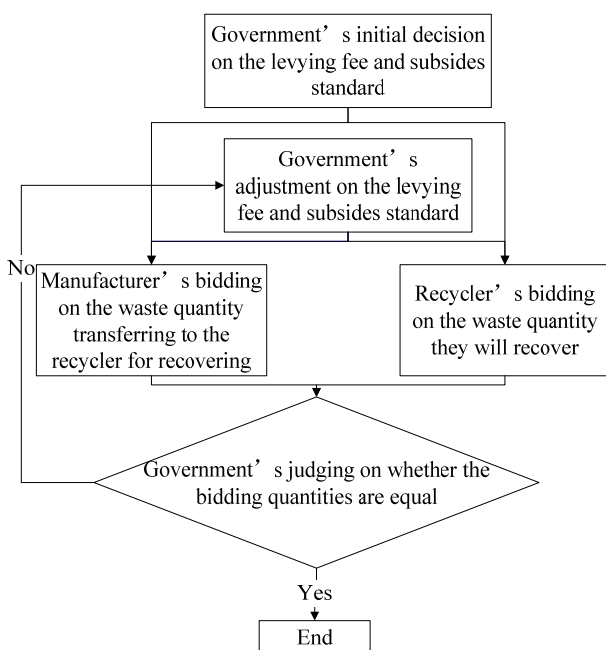

FIG. 1 THE MULTISTAGE NEGOTIONATION PROCESS

The specific process is illustrated as follows:

Initial Decision on the Standards

The government will make the decision on the levying fee standard that it will levy from the manufacturers, marked as p_1^0, as well as the subsidy standard for the recyclers, marked as p_2^0. And then it publics these standards for the manufacturers and recyclers to help them to make their recovering decisions.

Recovering Quantity' Bidding

After the manufacturer i received the information about the levying fee standard, it will decide how many waste products it will transfer to the recyclers for recovering according to Equ.9, and bids the number q_{q2i}^0 to the government. Meantime, the recycler j will also decide how many waste products it can recover, and also bid the number q_{sj}^0 to the government.

Standards Adjustment

In this process, the government adjust the levying fee standard and subsidy standard according to the numbers bided by the manufacturers and recyclers. The adjustment will base on the rule calibrated as,

If the total of the recovering waste products bided by the recyclers, marked as $\sum_{i=1}^{n} q_{g2i}^0$, is less than the total of the waste products that the manufacturers want the recyclers to recover, marked as $\sum_{j=1}^{m} q_{sj}^0$, that means the levying fee standard and subsidy standard are too low to encourage the recyclers' recovering behaviours, so these two standards should be adjusted to be higher. Defining the adjusting ratios are α_1^0 and α_2^0 respectively, the levying fee standard and subsidy standard for the next stage negotiation should be $p_1^0(1+\alpha_1^0)$ and $p_2^0(1+\alpha_2^0)$, and this will also be made public for the manufacturers and recyclers to help them to make their recovering decisions and also bid to the government.

End of the Negotioation

After several stages of negotiations, the whole negotiation will be ended when $\sum_{i=1}^{n} q_{g2i}^0$ is equal to $\sum_{j=1}^{m} q_{sj}^0$. Actually, this condition is too hard to realize,

so we define a similarity factor β, which can be calculated by

$$\beta = \frac{\sum_{j=1}^{m} q_{sj}^{0} - \sum_{i=1}^{n} q_{g2i}^{0}}{\sum_{i=1}^{n} q_{g2i}^{0}} \qquad (16)$$

And we also introduce a instant η, which is in the range of [0,1] to help us control the negotionation. If β is no more than η, we call that the $\sum_{i=1}^{n} q_{g2i}^{0}$ is similar to $\sum_{j=1}^{m} q_{sj}^{0}$, and the whole negotiation ends.

The Government's Bayesian Learning Model in Decision

In above negotiation, the quantity bidded by the manufacturers and recyclers in each stage is new information for the gorvenment, this is very useful for the government to update their previous knowledge. Bayesian learning model is an effective tool to help the negotiators in the negotiation process to update their knowledge[14], so it is used in this work to design the government's knowledge update process.

Bayesion Learning Model

The main role of the Bayesian learning model is to help learners update the understanding of learning objects by new information and use the new knowledge for decision-making, so as to improve the efficiency of negotiation. The update tool used is Bayesian formula, defined as:

There is a group of events A_i ($i=1, 2, …, n$) related to the event H, and they are satisfied:

(1) $P(A_i)>0$;

(2) $Ai \cap Aj \neq 0, i \neq j$;

(3) $\cup Ai = \Omega$;

Then the Bayesian formula can be defined as:

$$P(A_i / H) = \frac{P(H/A_i)P(A_i)}{\sum_{i=1}^{n} P(H/A_i)P(A_i)} \qquad (17)$$

Where $P(A_i)$ is called priorori probability. $P(H/A_i)$ is called conditional probability which means that the happening probability H when A_i happens. $P(H/A_i)$ is the amended probability and called posterior probability.

Elements of Government's Bayesian Learning Model

A complete Bayesian learning model should include the following components: learning object, priorori knowledge, conditional knowledge and posteriori knowledge. When we talking about the gorvenment learning process, these elements can be explained as:

1) Learning Objects

Because the final decision variables for the gorvenment are the equilibrium levying fee standard and the subsidy standard, so we selects them as the learning objects.

2) Priorori Knowledge

In every negotiation stage, the government will make the decision on its judgements on the distribution of equilibrium levying fee standard and the subsidy standard, and these forecasted distributions are prior knowledge.

3) Conditional Knowledge

When the government obtain the recovering quantity bidded by the manufactuers and the recyclers, it will make a comparison between these two levels accoding to the rule described in Fig.1. By this comparison the gorvenment can get a knowledge of the range of its learning objects, and this knowledge is the conditional knowledge.

4) Posteriori Knowledge

Combining the posteriori knowledge and conditional knowledge, the government can update its understanding of the distribution of levying fee standard and subsidy standard by the Bayesian formula, and these updated knowledge are called posteriori knowledge.

Government's Bayesian Learning Process

1) Deciding and Publishing the Levying Fee Standard and Subsidy Standards based on Priorior Knowledge

Suppose the government estimated that the probable distribution ranges of p_1^* are [0, λ_1], [λ_1, λ_2],…,[λ_{k-1}, λ_k]. We use event A_1 to demonstrate that p_1^* is in the range of [0, λ_1], and the same design for events A_2, …, A_k. $P(A_k)$ ($k=1,2, …, K$) is used to express the happening probability of event A_k ($k=1,2, …, K$), so we can get the expection of p_1^*, that is

$$E\left(p_1^*\right) = \sum_{k=1}^{K} \frac{\lambda_k + \lambda_{k-1}}{2} P(A_k) \tag{18}$$

When the same assumptions are used for p_2^*, and we design $P(B_l)$ $(l=1,2, \ldots, L)$ to express the happening probability of event B_l which means that p_2^* is ranged in $[\gamma_{l-1}, \gamma_l]$. So the expection of p_2^* is calculated by

$$E\left(p_2^*\right) = \sum_{l=1}^{L} \frac{\gamma_l + \gamma_{l-1}}{2} P(A_l) \tag{19}$$

The government will select $E\left(p_1^*\right)$ and $E\left(p_2^*\right)$ as its levying fee standard and subsidy standard and publish these numbers to the manufacturers and recyclers.

2) Obtaining the Conditional Probabilities Based on the Comparison of Manufacturers' and Recyclers' Rcovering Quantity' Bidding

After receiving the recovering quantity' bids from the manufacturers and recyclers, the government will find that there is gap between these two bids, and we call this event as H0. Based on this event, the government can estimate the happening probabilities of the event H0 on the condition that the equilibrium levying fees standard and subsidy standard distribute in the range of [λk-1, λk] and [γl-1, γl], and we use $P(H^0/A_k)$ and $P(H^0/B_l)$ to express the conditional probabilities.

3) Updating the Knowledge by Bayesian Learning Formula

After we got the numbers of P(Ak), P(Bl) and $P(H^0/A_k)$, $P(H^0/B_l)$, it can be very easy to got the numbers of $P(A_k/H^0)$ and $P(B_l/H^0)$, these are the updated knowledge and also the priorior konwlege for the next stage negotiation.

The Bayesian learning process will ended if the condition described by Equ.(16).

Simulation

Data Description

It is assumed that the government is negotiating the levying fee standard and subsidy standard with the manufacturers and recyclers on a particular waste electronic products. And the parameters of their annual recovering costs and returns are shown in Tab.1. Meanwhile, it is assumed that the waste electronic products produced by the manufacturers that is needed to be recycled are 100, 130, 150 and 300 thansand each year respectively. The similarity factor β defined should be no less than 3%.

TABLE 1 PARAMETERS OF RECOVERING COSTS AND RETURNS

Kinds	Serial	a (1,000RMB/Year)	b (1RMB/unit)	c (1RMB/unit²)	r (1RMB/unit)
Manufacturer	1	2300	100	38	350
	2	2100	120	49	430
	3	3000	90	45	540
	4	4200	80	31	500
Recycler	1	3000	70	29	490
	2	5500	60	51	590
	3	3900	65	38	550

The estimated distribution ranges of the leving fee standard by the government are, $A_1 = [0,100]$, $A_2 = [100,200]$, $A_3 = [200,300]$, $A_4 = [300,400]$, $A_5 = [400,500]$, and accordingly the probabilities are $P(A_1) = 0.1$, $P(A_2) = 0.2$, $P(A_3) = 0.2$, $P(A_4) = 0.3$, $P(A_5) = 0.2$. the estimated distribution ranges of the subsidy standard are, $B_1 = [0,100]$, $B_2 = [100,200]$, $B_3 = [200,300]$, $B_4 = [300,400]$, $B_5 = [400,500]$, and accordingly the probabilities are, $P(B_1) = 0.1$, $P(B_2) = 0.2$, $P(B_3) = 0.3$, $P(B_4) = 0.2$, $P(B_5) = 0.2$.

Simulation Process

1) Government's Publishing for the Initial Levying Fee Standard and Subsidy Standard

The government calculated the expectation of its estimating levying fee standard as 280 RMB per unit and the subsidy standard as 270 RMB per unit and publish them for the manufacturers and recylers.

2) The Recovering Decision Made by the Manufacturers and Recyclers

The manufacuters made their recovering decision according to the rules described by Equ.(8) and (9), and the results are shown in Tab.2. Meanwhile the recyclers also made their recovering decision based on the rule described by Equ.(14) and the results are shown in Tab.3.

TABLE 2 INITIAL DECISION OF MANUFACTURERS' RECOVERING

Serial of Manufacturers	Self-recovering (1,000 units)	Recovered by Recyclers (1,000 units)
1	69.7	30.3
2	60.2	69.8
3	81.1	68.9
4	112.9	187.1
Total	324.0	356.0

All the decision made by the manufacturers and recyclers will be bidded to the governements again for adjustment for the next stage of negotiation.

TABLE 3 INITIAL DECISION OF RECYCLERS' RECOVERING

Serial of Recyclers	Intended Recovering (1,000 units)
1	108.6
2	78.4
3	99.3
Total	286.4

3) Government's Adjustments on the Standards

It can be esasily found from Tab.2 and Tab.3 that the total quantity that the manufacturers bidded for being recovered by the recylers are more than the total quantity that the recyclers want to recover, this is defined as the event H^0, which means that that subsidy standard is too low to inspire the recyclers' recovering behaviour, so the government need to increase the subsidy standard and also the levying fee standard. By this adjustment, it can be inferred that the equilibrium levying fee standard does not distribute in the range of A1 and A2, so the case that event H0 can not appear when events A1 and A2 happen, that is $P(H^0/A_1) = 0$, $P(H^0/A_2) = 0$. It can be further estimated that $P(H^0/A_3) = 0.3$, $P(H^0/A_4) = 0.5$, $P(H^0/A_5) = 0.2$. The same inferring lines are applied for the subsidy standard and we can infer and estimate that $P(H^0/B_1) = 0$, $P(H^0/B_2) = 0$, $P(H^0/B_3) = 0.3$, $P(H^0/B_4) = 0.5$, $P(H^0/B_5) = 0.2$. these are the prior knowledge for the government's next stage decision.

4) Government's New Decision based on Updated Knowledge

According to the updated prior knowledge in last negotiation stage, the gorvenment make its new decision as, the levying fee standard is 351.6 RMB per unit and 341.95 RMB per unit.

And then the manufactuers and recyclers made their decisions on the recovering as process 2) described, the result is that after 4 more stages of negotiation, the manufacturers totally bid 316,100 units that they want the recyclers to recover, and the recyclers totally bid 319,000 units that they want to recover, the similarity factor is 1%, which is less than 3%. So it can be considered that the

equilibrium leving fee standard and subsidy standard are appear, which are 358.93 RMB and 351.19 RMB per unit.

Results Analysis

For better understanding, we divide the cases into three kinds as:

Case 1 describes the Nash Equilibrium under complete information.

Case 2 describes that the government takes the Bayesian learning in the negotiation process.

Case 3 describes that the government did not take any learning model to update its knowledge, and only increase or decrease the standards by 3% in every stage.

TABLE 4 COMPARISON OF THE SIMULATION RESULTS

Case	Levying Fee Standard (RMB/unit)	Subsidy Standard (RMB/unit)	Recovered by Manufacturers (1,000 units)	Recovered by Recyclers (1,000 units)	Rounds of Negotiation
Case1	352.28	352.28	310.5	319.5	——
Case2	358.93	351.19	316.1	319.0	5
Case3	365.34	352.29	312.9	319.4	10

The comparison results show that the multistage negotiation can make the final decisions be near to the Nash equilibrium. But the government's Bayesian learning can effectively short the negotiation time, and make the negotiation process more efficient.

Conclusions

The construction of waste electrical and electronic products recovering system in China is still in its infancy, many issues should be studied, one of which is how to set up the recovering fund gallery, and a multi-stage negotiation mechanism is designed in this work, the analysis shows that,

(1) the process for making the levying fee standard and subsidy standard is actually a game between the government, manufacturers and recyclers. The government's policy decisions will affect the behaviours of the manufacturers and recyclers, meanwhile their behaviours also affect the government's decision-making behavior;

(2) The multistage negotiation mechanism can help the government to get more knowledge about the

manufacturers and recyclers, so as to make more reasonable decision on the levying fee standard and subsidy standard;

(3)The Bayesian learning model can help the government get more accurate information, and the updated knowledge makes it negotiate more efficiently.

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Xinquan. Ge was born in Bengbu City, Anhui, China. He got his bachelor's degree at the Basic Department of Hefei Industrial University in January 1982, China. And he received his master's degree at the Beijing Graduate School of Shaanxi Institute of Mechanical Engineering in May 1988, China. His major field of study includes cicular economy and knowledge management.

His working experience is as follows:

Jan.1982 – Sep.1985, TEACHER, Shaanxi Institute of Mechanical Engineering Beijing Graduate Department

Sep.1995 – Sep.1996, VISITING SCHOOLAR, Business School of Auburn University

May. 1988 – Now, TEACHER, School of Business and Economics in Beijing Information Science and Technology University, No. 12 of the Qinghe Xiaoying East Road, Haidian District, Beijing, China